PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

Hiroo IKEGAMI et al.

Application No.: 09/581,253

Filed: June 26, 2000

Attorney Docket No.: OSY-0000

Examiner: R. Madsen

Art Unit: 1761

Confirmation No.: 5157

For: LOW POSITIVE PRESSURE CANNED FOOD HAVING AN INTERNAL PRESSURE INSPECTION APTITUDE AND CAN THEREFOR

DECLARATION UNDER 37 C.F.R. §1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Dr. Ken Takenouchi, being duly swomed, hereby declare and say that:

I am one of the Inventors/Applicants of the above-identified invention.

I was awarded a Master degree on March 24, 1984 from Osaka University and a Ph.D. degree on March 25, 2004 from Yokohama National University. I studied applied physics in Osaka University, which including acoustics, vibration measurement, frequency analysis, material mechanics, etc. I studied on "an analytical study on tapping inspection of a can" in Yokohama National University, which including fundamental analysis of can body, optimized design of can body.

I am an employee of TOYO SEIKAN KAISHA, LTD., the assignee of the above-identified application. I have worked on developments of technology for packaging container, including forming process of 2-piece can, tapping inspection system, liquid nitrogen filling system, design of can body suitable for tapping inspection, etc.

In support of patentability of the invention, I hereby submit to the United States Patent and Trademark Office the following two (2) documents that I had prepared either by myself or in concert with others:

1. Inventor's Comment about US Patent Application 09/581,253, dated July 8, 2004 (5 pages); and

2. Optimization of Can Bottom Shape for Retort Sterilization and Tapping Inspection by Statistical Design Support System, Transactions of JSCES Paper No. 20030021 by Ken Takenouchi, Junichi Takada, Hiroo Ikegami and Masaki Shiratori (6 pages).

I further declare that I have no direct financial interest in the present invention, other than as an employee of the assignee.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent resulting therefrom.

July 21, 2004
Date

Ken Takenouchi
Dr. Ken Takenouchi

Enclosures: Inventor's Comment about US Patent Application 09/581,253
Optimization of Can Bottom Shape for Retort Sterilization and Tapping Inspection by Statistical Design Support System

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Inventor's comment about US Patent Application 09/581,253

July 8, 2004

Dr. TAKENOUCHI Ken

First of all, the tapping inspection, which is the field of related technology of this application, is explained. Tapping inspection, which detects a change of can internal pressure due to spoilage or leakage, is the most popular safety test method for canned food. Though it is not yet popular in U.S.A. due to preference of pressurized carbonated beverages, the tapping inspection is widely used in Japan and Europe. Two major manufacturers of the tapping inspection machines are Toyo Seikan Kaisha, Ltd.[1] and Benthos Inc[2].

As I described in the previous inventor's comments dated October 24, 2002, the tapping inspection measures frequency of free vibration on flat circular plate part of can bottom excited by electromagnetic pulse. This method is based on the fact that fundamental frequency of elastic circular plate is changed by applied uniform load (i.e., pressure). Relations of the natural frequency of the circular plate f and the applied load p are expressed as follows by large deflection theory of elastic plate [3,4,5].

$$\frac{p}{E}\left(\frac{a}{h}\right)^4 = C_{LI}\frac{\sqrt{(f/f_L)^2-1}}{C_{VI}} + C_{NL}\left(\frac{\sqrt{(f/f_L)^2-1}}{C_{VI}}\right)^3 \qquad \text{(Eq.1)}$$

Here, f_L expresses linear natural frequency.

$$f_L = \lambda^2 \frac{h}{2\pi a^2}\sqrt{\frac{E}{12\rho(1-\nu^2)}} \qquad \text{(Eq.2)}$$

h: plate thickness a: radius of a circular plate

E: Young's modulus ρ : mass density

ν : Poisson's ratio

C_{LI}, C_{NL}, C_{VI}, and λ are constants decided by boundary condition, respectively.

As shown in these equations, sensitivity of tapping frequency towards can internal pressure is significantly affected by thickness h, circular plate radius a, material property (Young's modulus E, density...etc.), respectively. Fig. 1 shows a theoretical and experimental value of tapping calibration curve of a circular plate, having the same characteristics and dimension of a can body shown in the Example 1. As shown in Fig. 1, tapping calibration curve of the can body of this application has the boundary condition close to Clamped-Immovable.

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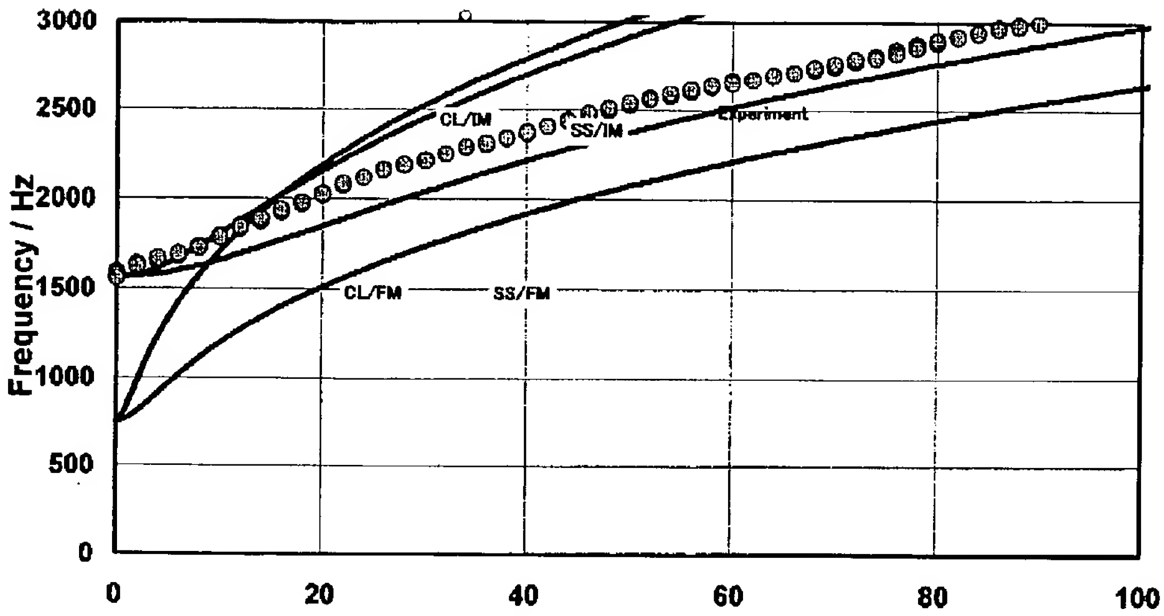

Fig.1 Theory and Experiment of Tapping Inspection

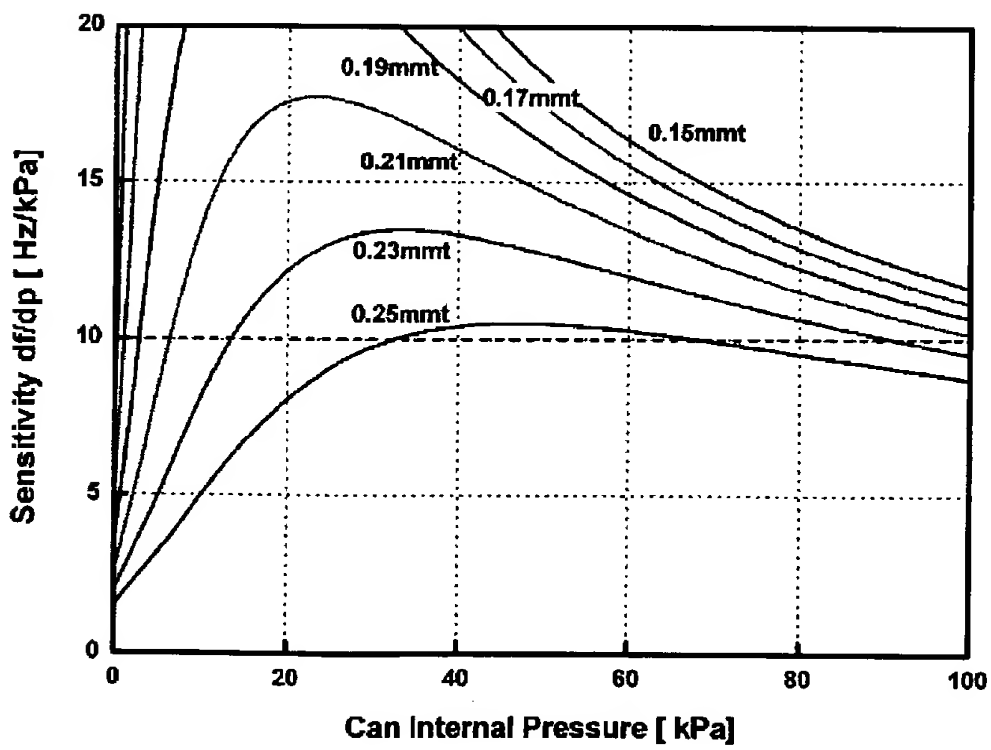

Fig.2 Theoretical Sensitivity of Tapping Inspection for Circular Plate.

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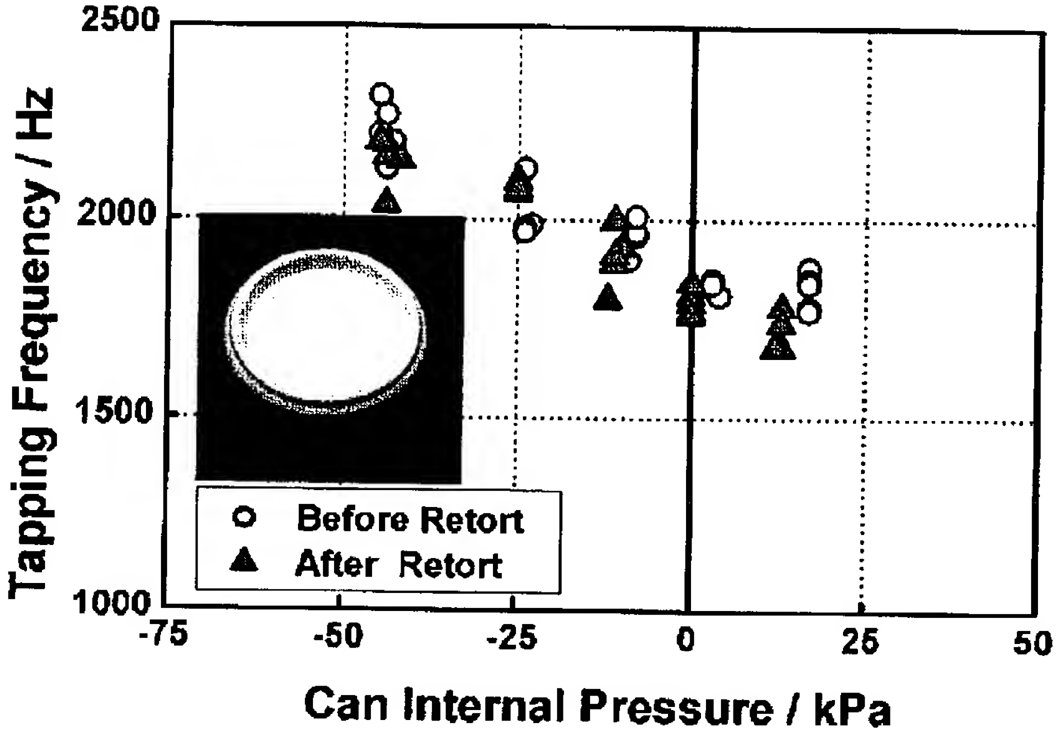
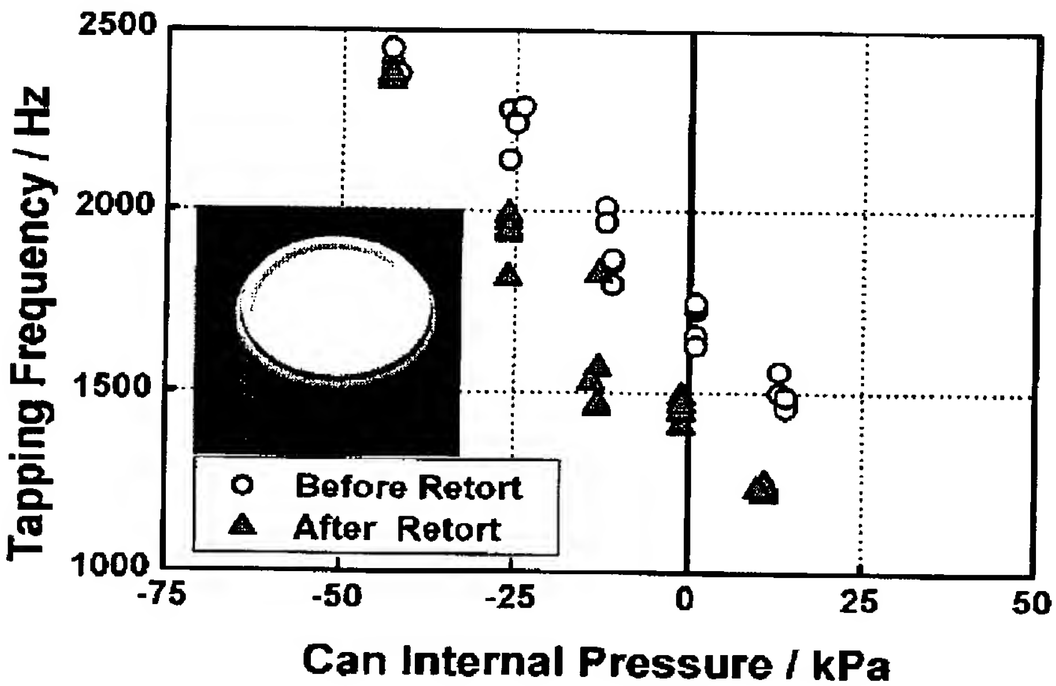


a) Bead Depth 0.74mm



b) No Bead

Fig. 3 Relationship between Bottom Profile and Tapping Inspection Aptitude After Retort Stalinization Process.

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It is required for can internal pressure measurement to detect a difference of 1kPa, while tapping inspection device has frequency measurement resolution of about 10Hz due to theoretical limitation of FFT used for frequency analysis process. Therefore sensitivity df/dp of tapping calibration curve, which is the property that an each can body type has, is required more than 10[Hz/kPa]. The sensitivity of the tapping calibration curves for circular plate having a radius of 18mm, which is the same size as the bottom center part described in Example 1, is shown in Fig.2 in various thicknesses. As shown in Fig. 2, bottom thickness equal to or less than 0.25mm is necessary in order to acquire enough sensitivity for this can body. However, it is difficult for the thin circular plate having the sensitivity to withstand the rise of can internal pressure during retort sterilization processes. The rise of the can internal pressure easily deforms the circular plate part of the can bottom, distorts the tapping calibration curve, and fails to compile the tapping inspection aptitude of the can body.

The can bottom shape having an annular bead of this application was invented so that the can bottom with the thin circular plate part having tapping inspection aptitude could acquire the pressure resistance to the pressure rise during the retort sterilization process. We have studied a relationship between can bottom shape of vacuum can and tapping inspection aptitude in detail [3,6]. Fig. 3 shows influence of the annular bead to the tapping inspection aptitude. Can bottom shape with an annular bead of 0.74mm deep, shown in Fig. 3a), has high pressure resistance such that the tapping calibration curve does not change after retort sterilization processing, though it has enough high sensitivity for can internal pressure. On the other hand, a tapping calibration curve of can bottom shape without an annular bead, shown in Fig. 3b), significantly changes after retort sterilization processing due to poor pressure resistance. This result indicates that formation of the annular bead is effective to acquire the pressure resistance so that it could overcome the pressure rise during retort sterilization process. Though it is limited in case of vacuum can, this study strongly suggests efficiency of this application for embodiment of a low positive pressure can.

Quoted references do not suggest any solution for the problem how to keep flat shape of a can bottom during retort sterilization processing. Thus there are no motivations to incorporate these references into my invention. Especially the patent of Leftault (U S P 4967538) has a completely different concept from my invention, because the patent is based on the concept which eliminates can body deformation due to the rise of can internal pressure by extending inside capacity when contents temperature is heating up (just after hot filling/seaming process, or retort sterilization

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process), and then pressurizes the can internal pressure by reforming the can bottom when contents temperature is cooling down. This patent does not have any information or knowledge in order to solve the problem described in my application. Therefore I insist that it is absolutely inappropriate to relate this patent with my invention.

Ref.:

1. Toyo Seikan Kaisha Ltd., 1-3-1 Uchisaiwaicho, Chiyoda-ku, Tokyo 100-8522 Japan, http://www.toyo-seikan.co.jp/
2. Benthos, Inc.49 Edgerton Drive o North Falmouth,MA 02556 USA, http://www.benthos.com/
3. Takenouchi, K., An Analytical Study of Tapping Inspection of a Can, Dr. thesis, Yokohama National University, 2004 (in Japanese)
4. Timoshenko, S. P., Woinowski-Kringer, S., Theory of Plates and Shells,2nd edn., Mcgraw-Hill, NY, pp.396-428(1959)
5. Ventsel, E., Krauthammer, T., Thin Plates and Shells, Marcel Dekker, NY,(2001)

Takenouchi, K., et al., Optimization of Can Bottom Shape for Retort Sterilization and Tapping Inspection by Statistical Design Support System, Transactions of JSCES,6,pp.77-82(2004)

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Transactions of JSCES, Paper No.20030021

Optimization of Can Bottom Shape for Retort Sterilization and Tapping Inspection by Statistical Design Support System.

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Two methods for evaluating tapping inspection aptitude of retort sterilized can body, Air Injection Method and FE Simulation Method, were developed. Optimum can bottom shape was investigated by the Statistical Design Support System combined with the FE Simulation Method. Depth of annular bead and bottom curvature were found to be dominant for each characteristic value. Evaluation results of the characteristic values for these optimum shapes by the FE Simulation Method and the Air Injection Method indicated qualitative consistency with those expected by optimization, and showed the improvement of tapping inspection aptitude of retort sterilized can body, as expected.
Keywords: Can, Tapping Inspection, Retort Sterilization, Optimization, Statistical Design Support System

1. Introduction.

Retort sterilization and tapping inspection are means for the assurance of canned products. During the retort sterilization process, canned products placed in pressure vessel are sterilized by high temperature steam. The temperature of heating steam, which is determined by the contents of canned products, is mostly kept in the range of 120-130°C. Can internal pressure rises with thermal expansion of contents. Although the relaxation techniques for can internal pressure behavior, such as air pressurized retort method, have been developed, it is required for can body to stand the rise of can internal pressure during retort sterilization process.

On the other hand, tapping inspection is a method to detect a change of can internal pressure, which is caused by leakage or spoilage, by detecting the change of the vibration frequency of can bottom. As shown in Fig.1, the vibration is excited by electromagnetic pulse on a flat circular part of can bottom. The frequency of can bottom vibration is analyzed by Data Extended FFT[1]. Can internal pressure is determined by the tapping frequency with previously measured tapping calibration curve, a relationship between the can internal pressure and the tapping frequency. Tapping inspection is based on the fact that the fundamental vibration frequency for circular plate part of can bottom indicates the can internal pressure. Therefore, high frequency sensitivity to the can internal pressure, which corresponds to the formation of circular flat part, is required for the can body.

However, these two requirements, high pressure resistance and high sensitivity, are in the relation of trade-off each other. For the lightweight can body, which has recently been required from economical and ecological point of view, it is important issue to meet these two requirements at the same time.

Moreover, on designing of new can body, it is necessary to predict a change of tapping frequency caused by can body deformation during the retort sterilization process. Tapping inspection aptitude after retort sterilization process for a proposed design has long been evaluated by experimental measurement of trial manufactures. However, as this approach is time and money consuming, it is difficult to extract an optimum design by testing many trial manufactures.

Recently, optimization method combined with computer simulation has been utilized extensively. Some studies on design optimization for improving acoustic and vibrational characteristics were reported[2][3].

In this study, two methods for evaluating the tapping inspection aptitude after retort sterilization process were developed. Furthermore, optimum can bottom shape was investigated with Statistical Design Support System. In order to verify the proposed approach, characteristic values of the optimum shape were evaluated.

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Manuscript received, June 23, 2003; final revision, August 20, 2003; published, September 1, 2003. Copyright ©2003 by the Japan Society for Computational Engineering and Science.

2. Methods for evaluating tapping inspection aptitude after retort sterilization process.

2.1 Air Injection Method. A test method for evaluating the tapping inspection aptitude of manufactured can body after retort sterilization process, named Air Injection Method (AIM), was developed. A test can body is connected with a pressure control equipment through a plug installed on a lid, which is the opposite side of vibration part by tapping inspection. On the first stage, can internal pressure is applied up to set pressure and kept for 3 minutes to induce can body deformation corresponding to the deformation occurred during retort sterilization process. On the second stage, tapping frequency of pressure-released can body is measured with controlling can internal pressure that corresponds to the initial can internal pressure. The above-mentioned procedure is conducted for several applied pressure levels. Relationships between the initial can internal pressure and the tapping frequency for each applied pressure indicate the tapping

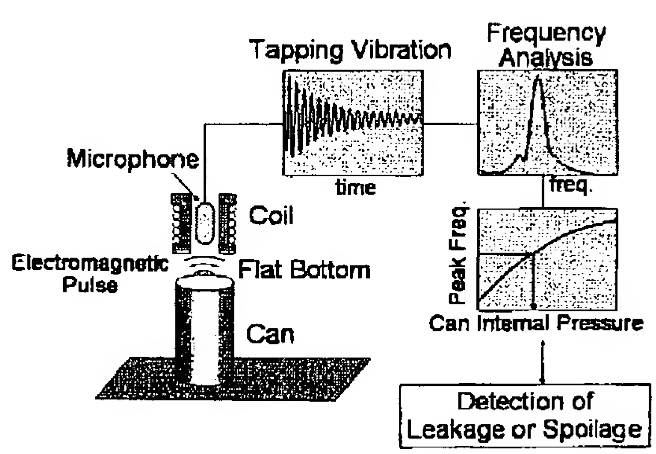
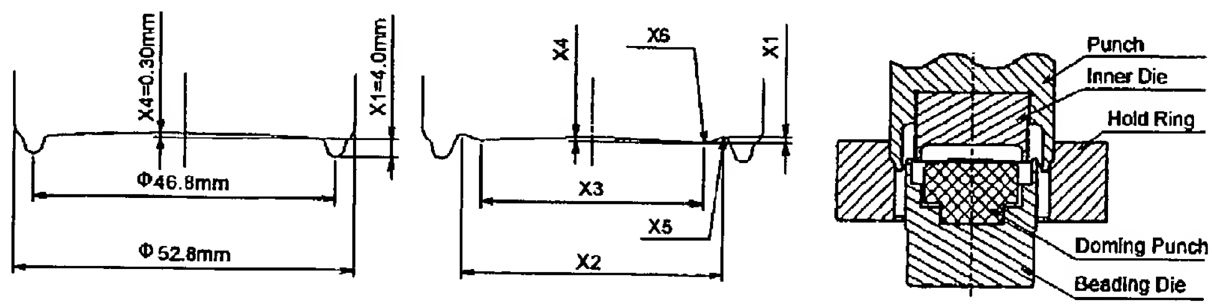


Fig. 1 Tapping Inspection System.



a) Conventional Shape b) Test Shape c) Forming Tool

Fig. 2 Cross sectional view of can bottom.

Table 1 Assignment of design factors to L27 orthogonal array and the resulting characteristic values obtained by FE Simulation Method.

No.	Design Factor													Character Value		
	X1 /mm	X2 /mm	e	e	X3 /mm	e	e	X4 /mm	X1*X4	X1*X4	X5 /mm	X6 /mm	e	Y1 /Hz	Y2 /kPa	Y3 /kPa
1	0.2	20.0	1	1	17.00	1	1	0.0	1	1	0.8	0.8	1	773	200	200
2	0.2	20.0	1	1	17.25	2	2	0.5	2	2	1.0	1.0	2	577	150	317
3	0.2	20.0	1	1	17.50	3	3	1.0	3	3	1.2	1.2	3	263	150	237
4	0.2	20.3	2	2	17.00	1	1	0.5	2	2	1.2	1.2	3	568	150	325
5	0.2	20.3	2	2	17.25	2	2	1.0	3	3	0.8	0.8	1	285	150	243
6	0.2	20.3	2	2	17.50	3	3	0.0	1	1	1.0	1.0	2	791	200	150
7	0.2	20.6	3	3	17.00	1	1	1.0	3	3	1.0	1.0	2	298	150	245
8	0.2	20.6	3	3	17.25	2	2	0.0	1	1	1.2	1.2	3	782	200	200
9	0.2	20.6	3	3	17.50	3	3	0.5	2	2	0.8	0.8	1	585	150	313
10	0.6	20.0	2	3	17.00	2	3	0.0	2	3	0.8	1.0	3	417	250	-10
11	0.6	20.0	2	3	17.25	3	1	0.5	3	1	1.0	1.2	1	500	200	362
12	0.6	20.0	2	3	17.50	1	2	1.0	1	2	1.2	0.8	2	251	150	300
13	0.6	20.3	3	1	17.00	2	3	0.5	3	1	1.2	0.8	2	463	200	378
14	0.6	20.3	3	1	17.25	3	1	1.0	1	2	0.8	1.0	3	261	150	325
15	0.6	20.3	3	1	17.50	1	2	0.0	2	3	1.0	1.2	1	461	250	-5
16	0.6	20.6	1	2	17.00	2	3	1.0	1	2	1.0	1.2	1	227	150	343
17	0.6	20.6	1	2	17.25	3	1	0.0	2	3	1.2	0.8	2	386	250	-10
18	0.6	20.6	1	2	17.50	1	2	0.5	3	1	0.8	1.0	3	518	200	362
19	1.0	20.0	3	2	17.00	3	2	0.0	3	2	0.8	1.2	2	188	350	-20
20	1.0	20.0	3	2	17.25	1	3	0.5	1	3	1.0	0.8	3	386	300	441
21	1.0	20.0	3	2	17.50	2	1	1.0	2	1	1.2	1.0	1	177	200	394
22	1.0	20.3	1	3	17.00	3	2	0.5	1	3	1.2	1.0	1	337	300	450
23	1.0	20.3	1	3	17.25	1	3	1.0	2	1	0.8	1.2	2	175	200	400
24	1.0	20.3	1	3	17.50	2	1	0.0	3	2	1.0	0.8	3	231	350	-15
25	1.0	20.6	2	1	17.00	3	2	1.0	2	1	1.0	0.8	3	131	200	440
26	1.0	20.6	2	1	17.25	1	3	0.0	3	2	1.2	1.0	1	163	350	-20
27	1.0	20.6	2	1	17.50	2	1	0.5	1	3	0.8	1.2	2	394	300	438

inspection aptitude of test can body after pressurization process.

This method is based on the fact that the deformation of can body during retort sterilization process occurs only by the effect of can internal pressure. Pressure application test has been adopted in evaluating the buckling pressure resistance of can body. Hence, the AIM can be adopted in evaluating the pressure resistance in terms of tapping inspection aptitude.

Although the AIM can save the trouble of retort sterilization process, it still requires to make trial manufactures of proposed can body design. It means that this method is still time and money consuming, and that the characteristics of proposed design cannot be evaluated until forming process is established.

In this study, the evaluations of proposed design by the AIM were conducted for the applied pressure level of 0kPa, 150kPa, 200kPa, 250kPa, 300kPa, 350kPa. The can bottom was buckled over 400kPa. The tapping frequency was measured by Tapping Detector PED-M1[4] (Toyo Seikan Kaisha, Ltd.).

2.2 FE Simulation Method. FE Simulation Method (FESM) was developed to evaluate the tapping inspection aptitude of the retort sterilized can body without any trial manufactures. On the first stage, deformation due to applied pressure for a FE model of proposed can body design is calculated by elasto-plastic analysis. On the second stage, the relationship between natural frequency of the deformed model and initial can internal pressure is calculated by eigenvalue analysis in consideration of large deflection. The above-mentioned procedure is conducted in several applied pressure levels. The relationship between the initial can internal pressure and the natural frequency (which is called "natural frequency curve" hereafter) for each applied pressure indicate the tapping inspection aptitude of proposed can body

design after pressurization process.

A commercially available FE Analysis software Marc (MSC. Software Ltd.) was used for the analysis. The FE model consisted of about 300 axisymmetric shell elements.

The tapping inspection aptitude of conventional can body was evaluated by both methods. The shape of conventional can body is shown in Fig. 2a). It was made of 0.260mm thick electrolytic chromium coated steel plate with laminated polyester film. The laminated film layer was neglected in the FESM because of its small Young's modulus. A good consistency between the results of both methods, as shown in Fig.4a) and 4b), means that the FESM was able to evaluate the tapping inspection aptitude as well as the AIM.

3. Optimization of can bottom shape by Statistical Design Support System.

Optimum can bottom shape for the tapping inspection aptitude after retort sterilization process was investigated by Statistical Design Support System (SDSS) combined with the FESM. SDSS is a kind of response surface method, in which a series of FE analyses are carried out under the planning of the design of experiments[5].

Test can bottom shape is shown in Fig. 2b). Following six dimensions were selected as design factors;

X1: Bead Depth, X2: Bead Diameter,
X3: Circular Part Diameter, X4: Bottom Curvature,
X5: Bead Ridge Radius, X6: Edge Radius.

Thickness, material property and basic dimensions shown in Fig.2a) were the same as those of conventional can body.

Following three characteristic values, corresponding to tapping inspection aptitude after retort sterilization process, were specified.

Y1: Sensitivity. Slope of natural frequency curve. In the tapping inspection system, accuracy of pressure measurement depends on accuracy of the tapping frequency measurement and the sensitivity. Higher sensitivity leads to higher accuracy of pressure measurement. In this study, difference between natural frequency for initial pressure -70kPa and that for 0kPa of applied pressure level 0kPa, corresponding to the curve characterized by the open circles in Fig. 4, was defined as the sensitivity.

Y2: Pressure Resistance. Maximum applied pressure at which natural frequency curve is unchanged from that of applied pressure level 0kPa. Plastic deformation induced by applied pressure over elastic limit gives significant change to the natural frequency curve. Pressure resistance, which indicates elastic limit, depends on material property, thickness, and initial bottom shape.

Y3: Inversion Resistance. Maximum applied pressure at which inversion point does not exist in the operation field (vacuum area in this study). The natural frequency curve has symmetry structure with respect to the inversion point, which corresponds to bottom curvature induced by the initial pressure. Monotonicity or nonexistence of inversion point in the operation field is required to determine can internal pressure from tapping frequency. The inversion resistance depends on the initial can bottom shape, the operation field and the deformation induced by applied pressure. The inversion resistance should be equal to or greater than the pressure resistance.

Optimum shapes were determined according to the rule that Y1 should be maximum under the constraint that Y2 and Y3 were greater than each critical value. By allocating each design factor to L27 orthogonal table, 27 shapes were analyzed by the FESM. The assignment of the design factors to the L27 orthogonal array was shown in Table 1, with the characteristic values obtained from the analyses. The response surface for each characteristic value was determined as follows;

$$Y1 = -21317.23 - 1235.00X1 + 416.67X1^2 + 3199.01X2 - 79.012X2^2 - 1258.89X3 + 38.22X3^2 - 903.04X4 + 171.92X4^2 + 548.33X5 - 302.78X5^2 + 99.17X6 - 40.28X6^2 + 3223.33X1X4 - 1953.33X1X4^2 - 1573.96X1^2X4 + 1002.08X1^2X4^2,$$

$$Y2 = 181.25 + 20.83X1 + 156.25X1^2 - 25.00X4 - 125.00X1X4,$$

$$Y3 = 10825.48 - 933.33X1 + 567.71X1^2 - 735.19X2 + 18.52X2^2 - 315.33X3 + 8.00X3^2 - 30.58X4 - 112.67X4^2 + 142.50X5 - 70.83X5^2 - 402.78X6 + 200.00X6^2 + 2840.00X1X4 - 1723.33X1X4^2 - 1393.75X1^2X4 + 850.00X1^2X4^2.$$

Table2 Effective ratio obtained by analysis of variance.

Factor	Effective Ratio / %		
	Y1	Y2	Y3
X1	42.4	51.0	52.2
$X1^2$	0.0	3.1	0.9
X2	0.0	0.0	0.2
$X2^2$	0.0	0.0	0.0
X3	0.4	0.0	0.3
$X3^2$	0.0	0.0	0.0
X4	25.5	37.5	0.9
$X4^2$	10.8	0.0	33.1
X5	0.2	0.0	0.1
$X5^2$	0.1	0.0	0.2
X6	0.0	0.0	0.1
$X6^2$	0.0	0.0	0.0
$X1 \times X4$	16.6	6.3	9.9
$X1 \times X4^2$	2.3	2.1	0.3
$X1^2 \times X4$	0.8	0.0	0.1
$X1^2 \times X4^2$	0.2	0.0	0.1
Error	0.8	0.0	1.5
Total	100.0	100.0	100.0

4. Results and discussions.

4.1 Optimum shape. Effective ratios of the design factors for the characteristic values, obtained from the analysis of variance, are summarized in Table 2. It was found from the analysis of variance that X1, depth of annular bead, and X4, bottom curvature, were dominant for each characteristic value, as shown in Table 2. The bottom shape was formed by press forming with forming tools shown in Fig. 2c). The dimensions X2, X3, X5, and X6 were determined by the shape of the forming tools, whereas X1 and X4 were determined by relative position of the tools at bottom-dead point of press machine. The result of the analysis of variance has shown that the characteristic values can be controlled without preparing forming tools of various dimensions. Throughout this study, using the same tool set, only the design factors X1 and X4 can be changed by controlling relative positions of the forming tools.

Fig. 3 shows a contour map of the characteristic value Y1,Y2, and Y3 for X1 and X4. In Fig. 3, Y1 increases towards lower left from upper right, Y2 towards upper left from lower right, and Y3 towards upper right from middle left, respectively. Hence, the constraints about Y2 and Y3 forms wedge-shaped area that spread from a crest at lower left,

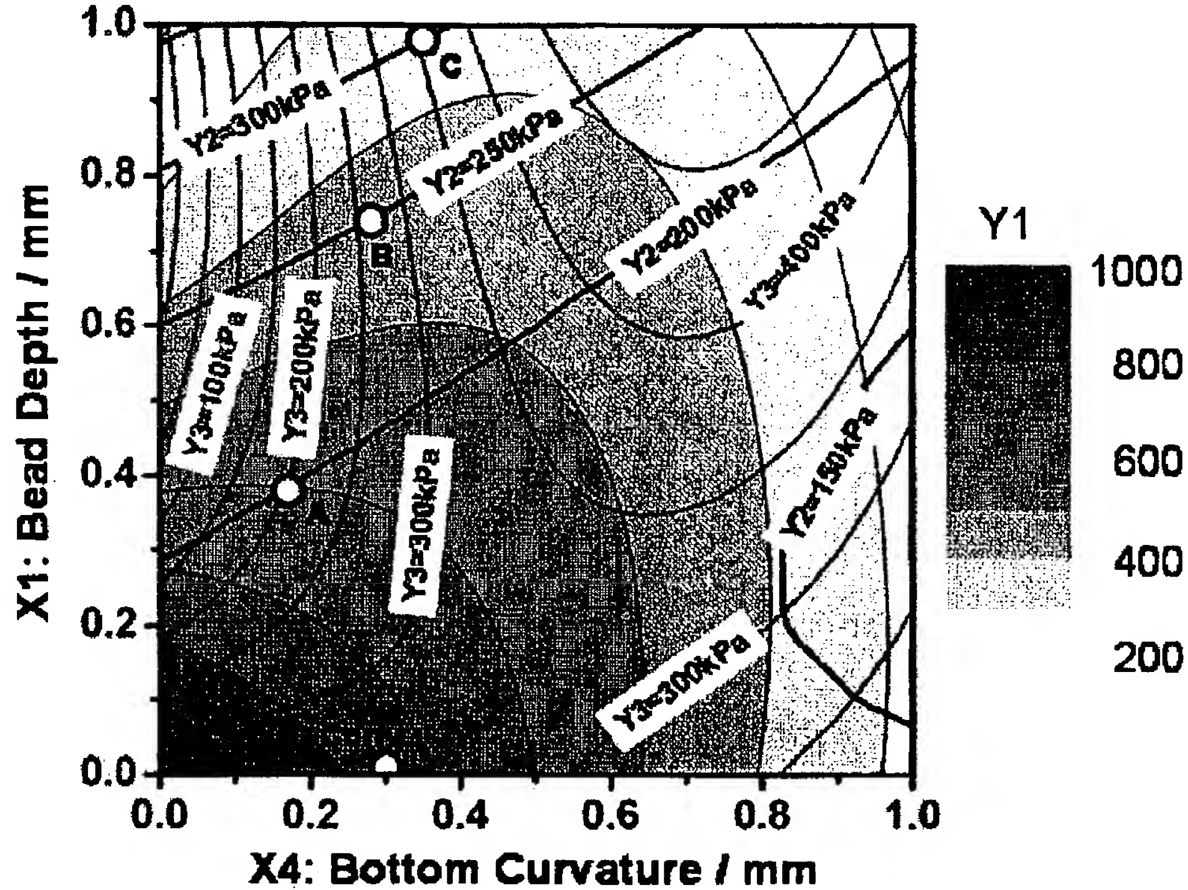


Fig.3 Distribution of characteristic value. Contour lines indicate the sensitivity, bold solid lines indicate the pressure resistance, and thin solid lines indicate the inverse resistance. Open Circles denote the determined optimum shapes.

where Y1 tends to be maximum.

Three optimum shapes, indicated by the symbols in Fig. 3, were determined by setting different critical values of Y2 and Y3. Each critical value of Y3 was set to be equal to that of Y2. Optimum shape A is for Y2 and Y3 =200kPa, optimum shape B for Y2 and Y3=250kPa, and optimum shape C for Y2 and Y3=300kPa, respectively. Optimum dimensions and expected characteristic values are summarized in Table 3. From optimum shape A to C, expected value of Y1 decreased as critical value of Y2 and Y3 increases.

4.2 Verification test. In order to verify the above results, the characteristic values of these optimum shapes were evaluated by the FESM, and further, by the AIM. Trial manufactures of optimum shapes were made from the same original plate for conventional can body. The results of the FESM and the AIM are shown in Fig. 4 and Table 3.

The result of the FESM showed decrease of Y1, with increase of Y2 and Y3, which can be observed in the change of these parameters starting from optimum shape A to C. This result was qualitatively consistent with that expected by SDSS. For Optimum shape A, the sensitivity Y1 of the FESM, 766Hz, was higher than that expected by the SDSS, 602Hz, the pressure resistance Y2, 200kPa, was unchanged, and the inversion resistance Y3, 250kPa, was higher than the SDSS critical value, 200kPa. For optimum shape B and C, the characteristic values obtained from the FESM also indicated higher sensitivity and higher inversion resistance than those expected from the SDSS. This means that the present response surface is not accurate enough to express the real response. Response surfaces that have higher order structure of design factor or further optimization in narrower area of design factors will lead more precise result.

The result of the AIM also showed decrease of Y1, with increase of Y2 and Y3 from optimum shape A to C, which was again qualitatively consistent with the results expected by SDSS. For optimum shape A, the sensitivity Y1 of the AIM, 520Hz, was lower than that expected by the SDSS, 602Hz, the pressure resistance Y2, 200kPa, was unchanged, and the inversion resistance Y3, 350kPa, was higher than the SDSS critical value, 200kPa. For optimum shape B and C, the

Table 3 Characteristic Values for Optimum Shapes.

Shape	Design Factors						Characteristic Values								
	Optimum Dimension / mm						SDSS			FESM			AIM		
	X1	X2 (fixed)	X3 (fixed)	X4	X5 (fixed)	X6 (fixed)	Y1/Hz (expected)	Y2/kPa (critical)	Y3/kPa (critical)	Y1 /Hz	Y2 /kPa	Y3 /kPa	Y1 /Hz	Y2 /kPa	Y3 /kPa
Opt. A	0.38			0.17			602	200	200	766	200	250	520	200	350
Opt. B	0.74	40.0	34.0	0.28	0.9	0.9	438	250	250	558	250	300	290	250	350
Opt. C	0.98			0.35			363	300	300	468	300	400	230	300	450
Conv.	0.00	40.0	40.0	0.30	-	-	-	-	-	925	150	200	800	100	250

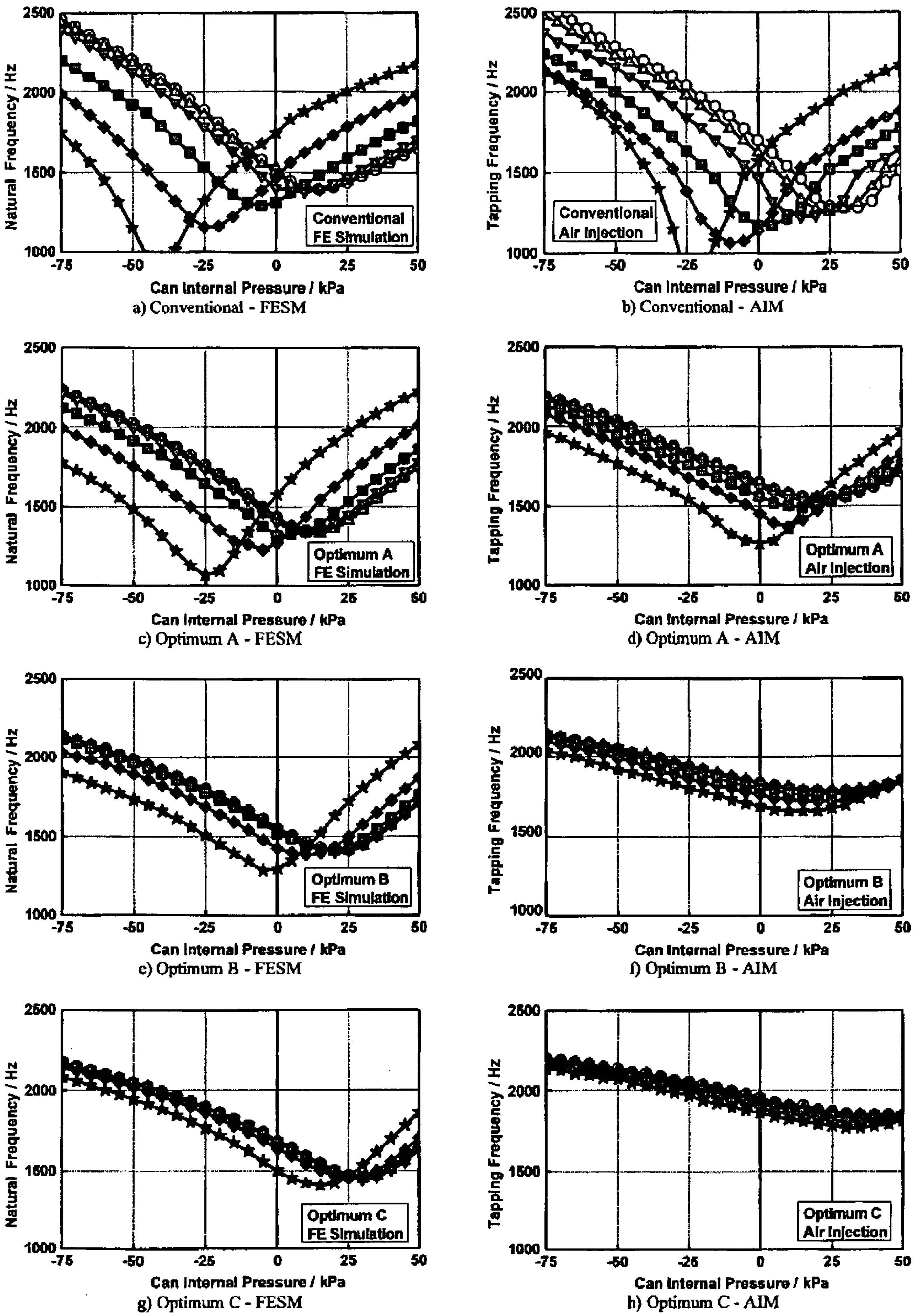


Fig. 4 Evaluation result of tapping inspection aptitude. Symbols of each figure indicate the applied pressure of 0kPa, 150kPa, 200kPa, 250kPa, 300kPa, 350kPa, respectively.

characteristic values obtained from the AIM also indicated lower sensitivity, higher pressure resistance and higher inversion resistance than those expected from the SDSS. The result of the AIM was affected by the accuracy of design parameters of the trial manufacture, which will be improved by refinement of the design of forming tool. Change of thickness and material property caused by the deformation process, as well as the deviation of dimension, should be considered for further precise optimization.

In practical operation of the tapping inspection system, can internal pressure has been determined by accuracy of 1kPa from the measurement of tapping frequency which has resolution of 10Hz. Hence, the slope of tapping calibration curve should be 10Hz/kPa, which corresponds to the sensitivity Y1 = 700Hz. The sensitivity of the conventional shape, which indicated in Table 3, was greater than the appropriate value. On the other hand, reinforcement of pressure resistance and inversion resistance have been required to bear the can internal pressure rise in the retort sterilization process, which has some fluctuations over the cans in the retort vessel due to deviation of temperature or contents volume of each can, etc. The result of FESM showed that the optimum shape A indicated the reinforcement of Y2 and Y3 with allowable sacrifice of Y1 from the conventional shape. Although the result of the AIM indicated the sensitivity Y1 smaller than the appropriate value, further optimum shape will be obtained by adjusting the critical values of Y2 and Y3 because the results of the AIM were qualitatively consistent with those expected by SDSS. The relationship between the tapping inspection aptitude and the design factors obtained in this study is difficult to acquire by conventional design procedure because it requires many experiments of trial manufactures.

5. Conclusion.

Two methods for evaluating tapping inspection aptitude of retort sterilized can body, the Air Injection Method (AIM) and the FE Simulation Method (FESM), were developed. The AIM simulates the deformation during retort sterilization process by injecting air into the trial manufacture of can body, while the FESM simulates it by elasto-plastic analysis.

Optimum can bottom shape for the tapping inspection aptitude after retort process was investigated by the Statistical Design Support System (SDSS) combined with the FESM. Three characteristic values, sensitivity, pressure resistance, and inversion resistance were specified. Response surfaces of six design factors for these characteristic values were derived from SDSS. The depth of annular bead and the bottom curvature were found to be dominant for each characteristic value. Three optimum shapes were derived by setting three different levels of critical values of pressure resistance and inversion resistance.

The characteristic values of these optimum shapes were evaluated by the FESM, and further, by the AIM. The results for the optimum shapes indicated qualitative consistency with those expected from optimization, and indicated the possibility for the improvement of tapping inspection aptitude after retort sterilized process, as expected.

The proposed procedure will contribute to improve the efficiency of can body design process by saving trial manufacturing, which is time and money consuming.

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